

charge at Milwaukee to obtain, if possible, the desired information. Replies to his letter of inquiry were received from Masters Bahle, Robertson, and Van Dyke, that of Master Bahle<sup>1</sup> being given below:

With the wind west and the weather clear we may have vapor or steam, as we call it, part way or all the way across the lake. All depends on the difference in the temperature of the water and the air. During the early part of winter, say in December, when the water is not the coldest, the weather will moderate as we reach the east shore or as we near the east shore and this will cause the steam (fog) to rise off the water entirely in clouds and then snow may fall. I have seen this anywhere from the middle of the lake to the east shore. Later in the winter when the water becomes real cold and the air temperature say about 15° below zero on the west shore, the steam (fog) may reach the east shore and snow there also, the snow not extending out in the lake more than 2 or 3 miles. In other words, it does not snow when the steam (fog) makes. It starts to snow where the steam (fog) stops making and starts to rise in clouds entirely away from the water.

Masters Robertson and Van Dyke both wrote that steam or fog rising on the western shore of the lake means snow on the eastern shore, and that these flurries

extend back 10 to 20 miles from the eastern shore, as a rule.

The cold air from the west reaches Lake Michigan with a temperature considerably below freezing and sweeps out over the lake, the water of which has a temperature of nearly 40° early in December and approximately 32° during January and February. It appears, therefore, that there is a layer of warmer air immediately over the lake under these conditions, being necessarily quite shallow along the western shore and increasing in depth toward the east, and that convectional currents and turbulence set in, manifesting themselves in the form of vapor near the western shore, in the formation of clouds farther out in the lake and, eventually, precipitation in the form of snow flurries where convection and turbulence are sufficient to produce it.

The accompanying illustration by Mr. W. P. Day (p. 502) shows graphically the manner in which clouds and precipitation are brought about.—C. L. Mitchell.

# A SIMPLE FILLING APPARATUS FOR DEFINITE INFLATION OF PILOT BALLOONS.

By R. C. LANE, Observer.

[U. S. Weather Bureau, Washington, D. C., Aug. 30, 1921.]

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## SYNOPSIS.

*Indefinite and definite inflation of pilot balloons for aerological observations.*—The rate of ascent at which pilot balloons rise in the free air is determined from the formula

$$V = 72 \left( \frac{l}{L} \right)^{\frac{1}{2}}$$

where  $V$  is the rate of ascent in meters per minute,  $l$  is the free lift in grams of the inflated balloon, and  $L$  is the total lift of the confined gas. The character of the formula is such that it is impracticable for the average observer to solve for either  $l$  or  $L$ , with respect to any given or desired value of  $V$ . Up to this time inflation can be defined as *indefinite*, wherein the rate of ascent has been dependent upon the weight and free lift of the inflated balloon, and the magnitude of the rate could not be controlled by the observer except within narrow limits. By means of the apparatus herein described the author makes a convenient and valuable transposition, wherein the free lift of the balloon for any desired rate of ascent is dependent upon the weight of the balloon and the rate of ascent selected. This provides a method of *definite* inflation wherein the observer is able to select any rate of ascent suitable to the fancy or to the current meteorological conditions, and inflate the balloon accordingly. The process of inflation is thereby resolved to the equivalent mechanical operation of the method, earlier used.

Since the earlier stages of pilot balloon observation work, the need of some efficient apparatus for the inflation of balloons to a particular rate of ascent has been generally felt, and this need has increased with the rapid development of observation work. The apparatus here disclosed has been devised after considerable study of various methods and after much experimental work. The simplicity of the arrangement and the purely mechanical manipulation of the apparatus in practice, with the small amount of machine work necessary in construction, should tend toward the general use of such an apparatus in observations with pilot balloons.

At present, balloons, when inflated with hydrogen, are assumed to rise with a nearly constant rate of ascent. In the United States, the rate  $v$ , at which they are assumed to ascend, is computed by a formula which takes into account the weight  $w$ , in grams, of a rubber balloon expelled of air; the free lift  $l$ , or the mass in grams that

the inflated balloon will just sustain; the total lift  $L$ , ( $w + l$ ), or the entire mass in grams that the confined gas will support; and a constant 72, determined by a careful study of numerous double-theodolite observations. The formula expressing the rate of ascent was devised by the Meteorological Section of the Signal Corps, and is as follows:

$$V = 72 \left( \frac{l}{L} \right)^{\frac{1}{2}} \quad (1)$$

Pilot balloons are inflated according to either of two methods. One may be known as indefinite inflation, and the other as definite inflation. By the method of indefinite inflation the balloon is first weighed, then inflated with gas to near some particular diameter, the free lift of the inflated balloon measured, and the rate of ascent computed from these data by the formula. The resulting rate of ascent may be any odd value. By the method of definite inflation, some convenient rate of ascent is determined, the balloon is then weighed, the amount of free lift necessary for that particular rate of ascent and weight is then determined, and the balloon inflated accordingly.

Inflation by the definite method is superior to the indefinite since it enables one to inflate to any desired rate of ascent. In view of this fact, a rate of ascent of 200 m./min. or any other rate in which the successive multiples end in one or more zeros, will materially increase the ease, speed, and accuracy of computation in determining the horizontal distance of the balloon from the observation point. Whether the computation be made by slide rule or by graphical means, the above statement is equally true. As an illustration, suppose the altitude of a balloon at the end of some particular minute when inflated by the indefinite method is 3151 meters, and by definite inflation we have an altitude of 3300 meters for the corresponding minute. The number 3300 can be set more quickly and accurately on the slide rule than can the number 3151. Experience has proved that the definite inflation method will not only insure accuracy and speed, but will truly permit a higher quality of work in general.

Definite inflation is more difficult to attain than indefinite inflation and is practically impossible without the aid of some specially designed apparatus. The character of the formula by which the rate of ascent is computed,

<sup>1</sup> The following interpretation is put upon the letter reproduced above: In December when the water is warmer than the overlying air surface air coming from the west becomes warmer as it passes over the lake and gains distance toward the east until finally it reaches a point over the lake when the contrast in temperature between air and water is not sufficient to form fog. By this time, however, vertical convection has carried the moisture of the fog high enough to be condensed as snow and this is probably the explanation of the statement—it does not snow when fog makes; it starts to snow when the fog stops making and starts to rise in clouds.

Evidently there are times also when the fog extends from shore to shore; at these times there may be snow on the east shore.—EDITOR.

is such that the free lift  $l$ , can be determined only by a laborious method too long and deeply involved to permit of rapid application. Therefore, tables for selected rates of ascent have been computed and only recently published as Table 28, in *Instructions for Aerological Observers*, by the United States Weather Bureau.

The equipment necessary for indefinite inflation consists of little else than a hydrogen line terminating in a short length of soft and rather pliable rubber tubing leading to a suitable nozzle upon which the balloons may be secured, all adapted to a delicate balance, and weights with which to determine the weight,  $w$ , and lifting power,  $l$ , of the balloon. The apparatus for definite inflation requires but little more. However, some alteration in the equipment and a complete reversal of the operation are necessary. The hydrogen line and nozzle must be carried to and installed upon the balance. Extreme care must be given to this installation so that the sensitivity of the balance may not be interfered with. An efficient filling apparatus must be both sensitive and accurate.

The function of such an apparatus is to attain the exact amount of free lift for a balloon of given weight so that it may ascend at some predetermined rate. The amount of free lift required corresponding to weight and rate of ascent can be found in Table 28, *Instructions for Aerological Observers*. The remaining problem then is to bring the inflation to that point, and is accomplished by securing the balloon to the nozzle on one pan of the balance, establishing equilibrium of the beam system or weighing of the balloon, applying a definite load to the same pan of the balance to which the balloon is secured, and allowing the gas to flow until equilibrium of beam system is again established.

The amount of necessary alterations of the balance will depend upon the type of balance used in the regular observation work. The type of balance used in pilot balloon observations by the United States Weather Bureau is supplied by the Central Scientific Co. of Chicago, Ill., and is catalogued as No. 652, "Dispensing and Solution Scale." The method and apparatus developed in this paper require very little alteration of that balance, and may be grouped as (a) hydrogen line support, (b) nozzle assembly, (c) free lift scale bar.

The hydrogen line support consists of one end of the main hydrogen line rigidly secured to the balance frame so that it does not detract from the sensitivity of the beam system. The nozzle assembly consists of a suitable terminal of hydrogen line affixed to the left hand pan of the balance, upon which the balloon may be placed for inflation. The free-lift scale bar consists of a carefully graduated bar, carrying a 20 gram rider, rigidly fixed to, and parallel with the beam system of the balance. In conjunction with the latter, provision is made for the application of a weight of a certain mass to the nozzle end of the beam system.

The principle of the filling apparatus under discussion is founded upon the equivalent moments of force on either side of the fulcrum of a simple lever. Suppose the length of the arms of the balance beam to be  $a$  and  $b$ . Fig. 1. Now, since a balloon inflated with hydrogen will exert a lifting force,  $l$  (free lift), let us apply a weight,  $m$ , of some convenient and known mass to the same arm of the system. By reference to Table 28, *Instructions for Aerological Observers*, it will be seen that the element  $l$ , will vary for the ascensional rate depending upon the weight of the balloon that is being inflated, and therefore, the difference between the lifting force,  $l$ , and the applied mass,  $m$ , will also vary. Let this difference be known as  $r$ , the amount of variation to be accounted for

by the free-lift scale bar and rider. Both  $l$ , and  $m$ , act through the arm  $a$  and opposite to each other; the difference between their working forces measures the magnitude of  $r$ . Now, by the laws of the simple lever.

$$(m-l)a = rb \quad (2)$$

In the balance used,  $a$  and  $b$  are equal and might be factored out of the equation, but the final development of the apparatus requires that they be retained. The element  $l$  is found in Table 28, already mentioned; and  $m$  will be any convenient weight, remaining the same for any one rate of ascent; it may be greater or less in mass than  $l$ .

To inflate a 15-gram balloon to ascend at a rate of 200 m./min. we require a free lift,  $l$ , Table 28, *Instructions for Aerological Observers*, of 161.1 grams. The weight of  $m$ , designed for the 200 m./min. rate is 200 grams. The difference between these forces amounts to 38.9 grams and acts through a distance of 10 centimeters from the fulcrum. Substituting these values in formula (2), it is obvious that 389.0 gram-centimeters of force must be added to the arm  $b$  in order to establish equilibrium throughout the system. With an unaltered balance it would be necessary to place a mass of 38.9 grams upon the pan at the end of arm  $b$ , but by the method under

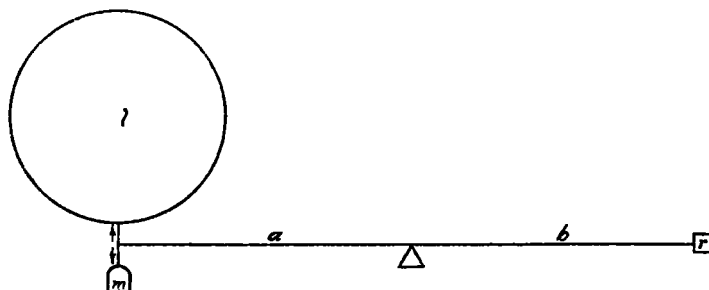


Fig. 1.—Schematic drawing showing the principle of the simple lever as applied to the free lift and rider adjustments used in overcoming the moment of a constant mass.

development, the entire operation is mechanical and no attention need be given to the deduction of differences, nor to the selection of weight to satisfy the force  $r$ ; thus two sources of error are eliminated. In this respect the apparatus is automatic.

Figure 2 shows the arrangement of the apparatus. The balance in standard use is provided with a hydrogen line support inserted through a hole in the base casting. The assembled support consists of a piece of  $\frac{1}{2}$ -inch brass rod 7 inches long, with  $\frac{3}{8}$ -inch pipe thread on one end. On this threaded end of support is screwed a  $\frac{3}{8}$ -inch brass T, carrying a short piece of  $\frac{3}{8}$ -inch pipe on one side, and a three-way stop cock and reducer on the other. The post of the assembly is inserted in the base of the balance and secured by means of a set screw.

The nozzle assembly consists of a specially designed brass L. One arm of the L is extended through the bend to terminate in a screw and nut. On the opposite end is placed a wooden nozzle about 2 inches in diameter on which the balloon is secured. The remaining arm of the L is fitted with a reducer. The threaded end of assembly is then passed through a hole in the center of the left-hand scale pan and secured by aid of the nut. The reduced portions of the L and the three-way stop cock are then connected with a 15-inch piece of  $\frac{1}{2}$ -inch soft rubber tubing.

The free-lift scale bar consists of a brass bar  $16\frac{1}{2}$ " by  $\frac{1}{2}$ " by  $\frac{1}{8}$ ", carefully milled and graduated, and carries a 20-gram rider. Two holes  $\frac{1}{8}$  inch and countersunk are

drilled through the bar 3 inches on either side from the mid-point for securing the bar to the beam system of the balance in place of the 10-gram graduated beam with which the balance is originally equipped. Associated with the arrangement of this bar may be considered the support for the weight,  $m$ , for the magnitude of the weight will affect the position of the graduations on the bar. This support may consist of a ring or hook on the underside of and in line with the knife edge of the left-hand scale pan; or the supporting hook may be entirely dispensed with and the weight  $m$  so fashioned that when it is placed on the upper side and in the center of the pan it will fit closely about the stem of the nozzle assembly.

The mass of the weight,  $m$ , to be used for any one particular rate of ascent should be near the mean of the free lifts for the maximum and minimum weights of balloons that are likely to be inflated to that rate of ascent. With a rate of 200 m./min. for weights of balloons from 15 grams to 80 grams, inclusive, it was found that a mass of 200 grams was best adapted for the weight  $m$ . For inflations to a rate of 180 m./min. for the limits of weight from 15 to 80 grams, a mass of 140 grams seems best for the weight,  $m$ . The free lift scale for 200 m./min. and 180 m./min. rates have been graduated accordingly. Using weights of those magnitudes enables us to confine the length of scale bars to 16 inches and 14½ inches, respectively, with about half of the graduations on either side of the mid-point of the bar. It is hardly practicable to use a weight of 200 grams for the 180 m./min. rate for the necessary length of the bar would be greatly increased; a bar 37 inches long would be required.

The positions for each graduation on the scale bar were determined by a special method of computation. For the various weights of a balloon from 15 to 80 grams, inclusive, the amount of free lift necessary to give the particular rate of ascent was worked out to the fractional part of a gram in the third place. These data after reducing and checking gave the result under  $e$  of the accompanying table. Since weights of 140 grams and 200 grams had been selected as the mass of  $m$ , for rates of ascent of 180 and 200 m./min., respectively, and since these weights were always to be used for those particular rates of ascent, there would be a difference between these masses and the free lift for the various weights of balloons. The third and seventh columns, headed 10 (140- $l$ ) and 10 (200- $l$ ) give these differences reduced to gram-centimeters of force for the 180 and the 200 rate, respectively.

It was decided that a 20-gram rider was the most convenient size to be used since the scale graduations could then be included within the extremities of a bar 16½ inches long with an average distance of 11.0 millimeters between each gram division. Therefore, to determine the position on the scale bar for the rider, so that it would overcome the difference in moments of force, it would be necessary to divide that number into the difference. Substituting these values in formula (2), and solving for  $b$  we obtain the distance from the mid-point of free lift scale bar that the rider must be placed to overcome the difference in moments of force. The last two columns of the table under each rate of 180 m./min. and 200 m./min. give the position or distances of graduates from the mid point of bar for the corresponding weights of balloons. These distances are given in the table both in millimeters and in inches. Whether the graduations will be placed to the right or

to the left of the mid-point of the bar is determined by the character of the difference in the moments of force. If its moments of the free lift are less than the moments of the weight  $m$ , then the difference in moments between these two must be added to the right hand pan to establish equilibrium when the balloon is inflated to that lift; again if the moments of the free lift are more than the moments of the weight  $m$ , the applied weight  $m$  will be insufficient to measure that amount of free lift and the difference in moments must be added to the left hand pan of the balance. Therefore, let the minus signs of Table 1, indicate values to the left of the mid point of scale bar. The free lift scale bar in figure 2 is graduated for an ascensional rate of 200 m./min. Table 1 gives the data for graduating the free-lift scale bar for rates of 180 m./min. and 200 m./min. in both English and metric units.

TABLE 1.—Showing distance of graduations from mid point of free-lift scale bar, for ascensional rates of 180 and 200 meters per minute.

Weight ( $w$ )	Rate 180 meters per minute.				Rate 200 meters per minute.			
	Free lift ( $l$ )	10 (140- $l$ )	Position of rider.		Free lift ( $l$ )	10 (200- $l$ )	Position of rider.	
	g.	g.-cm.	mm.	in.	g.	g.-cm.	mm.	in.
15.....	103.96	340.4	170.20	6.70	161.09	339.1	194.55	7.66
16.....	107.32	326.8	163.40	6.43	162.73	372.7	186.35	7.35
17.....	108.70	313.0	156.50	6.16	164.30	357.0	178.50	7.04
18.....	110.06	299.4	149.70	5.90	165.77	342.3	171.15	6.74
19.....	111.37	286.3	143.15	5.64	167.27	325.3	162.65	6.45
20.....	112.70	273.0	136.50	5.38	168.69	313.1	156.55	6.16
21.....	113.95	260.5	130.25	5.13	170.23	297.7	148.85	5.90
22.....	115.19	248.1	124.05	4.88	171.72	282.8	141.40	5.57
23.....	116.45	235.5	117.75	4.64	173.17	268.3	134.15	5.29
24.....	117.71	222.9	111.45	4.39	174.57	254.3	127.15	5.01
25.....	119.03	209.7	104.85	4.14	175.87	241.3	120.65	4.74
26.....	120.32	197.8	98.90	3.89	177.35	229.5	113.25	4.46
27.....	121.43	185.7	92.85	3.65	178.70	213.0	106.50	4.19
28.....	122.66	173.4	86.70	3.41	180.07	199.3	99.65	3.92
29.....	123.86	161.4	80.70	3.18	181.43	185.7	92.85	3.66
30.....	125.01	149.9	74.95	2.95	182.72	172.8	86.40	3.40
31.....	126.15	138.2	69.10	2.72	184.07	159.3	79.65	3.14
32.....	127.33	126.7	63.35	2.49	185.38	146.2	73.10	2.88
33.....	128.45	115.5	57.75	2.27	186.62	133.8	66.90	2.63
34.....	129.57	104.3	52.15	2.05	187.93	120.7	60.35	2.37
35.....	130.69	93.1	46.55	1.83	189.28	107.2	53.60	2.11
36.....	131.77	82.3	41.15	1.62	190.60	94.0	47.00	1.85
37.....	132.86	71.4	35.70	1.41	191.88	81.2	40.60	1.60
38.....	133.97	60.3	30.15	1.19	193.13	68.7	34.35	1.35
39.....	135.09	49.4	24.70	.98	194.38	56.2	28.60	1.11
40.....	136.10	39.0	19.50	.77	195.60	44.0	22.00	.87
41.....	137.17	28.3	14.15	.56	196.88	31.2	15.60	.62
42.....	138.24	17.6	8.80	.35	198.11	18.9	9.45	.37
43.....	139.23	7.7	3.85	.15	199.33	6.7	3.35	.13
44.....	140.30	-3.0	-1.50	-.06	200.51	-5.1	-2.55	-.10
45.....	141.31	-13.1	-6.55	-.26	201.69	-16.9	-8.45	-.33
46.....	142.32	-23.2	-11.60	-.46	202.85	-28.8	-14.40	-.56
47.....	143.33	-33.3	-16.65	-.66	204.03	-40.3	-20.15	-.79
48.....	144.35	-43.5	-21.75	-.86	205.20	-52.0	-26.00	-1.02
49.....	145.36	-53.6	-26.30	-1.05	206.39	-63.9	-31.95	-1.26
50.....	146.35	-63.5	-31.75	-1.25	207.59	-75.9	-37.95	-1.49
51.....	147.31	-73.1	-36.55	-1.44	208.76	-87.6	-43.80	-1.72
52.....	148.31	-83.1	-41.55	-1.64	209.92	-99.2	-49.60	-1.95
53.....	149.30	-93.0	-46.50	-1.83	211.07	-110.7	-55.35	-2.18
54.....	150.26	-102.6	-51.30	-2.03	212.19	-121.9	-60.95	-2.40
55.....	151.21	-112.1	-56.05	-2.22	213.32	-133.2	-66.60	-2.62
56.....	152.18	-121.8	-60.90	-2.40	214.43	-144.3	-72.15	-2.84
57.....	153.13	-131.3	-65.65	-2.58	215.54	-155.4	-77.70	-3.06
58.....	154.06	-140.6	-70.30	-2.76	216.64	-166.4	-83.20	-3.28
59.....	155.01	-150.1	-75.05	-2.94	217.75	-177.5	-88.75	-3.49
60.....	155.91	-159.1	-79.55	-3.13	218.87	-188.7	-94.35	-3.71
61.....	156.83	-168.3	-84.15	-3.31	219.94	-199.4	-99.70	-3.93
62.....	157.74	-177.4	-88.70	-3.49	221.02	-210.2	-105.10	-4.14
63.....	158.64	-186.4	-93.20	-3.67	222.10	-221.0	-110.50	-4.35
64.....	159.56	-195.6	-97.80	-3.85	223.19	-231.9	-115.95	-4.56
65.....	160.49	-204.9	-102.45	-4.03	224.29	-242.9	-121.45	-4.78
66.....	161.43	-214.3	-107.15	-4.22	225.35	-253.5	-126.75	-4.99
67.....	162.35	-223.5	-111.75	-4.40	226.42	-264.2	-132.10	-5.20
68.....	163.27	-232.7	-116.35	-4.58	227.49	-274.9	-137.45	-5.41
69.....	164.15	-241.5	-120.75	-4.75	228.55	-285.5	-142.75	-5.62
70.....	165.03	-250.3	-125.15	-4.93	229.58	-295.8	-147.90	-5.82
71.....	165.90	-259.0	-129.50	-5.10	230.61	-306.1	-153.05	-6.03
72.....	166.75	-267.5	-133.75	-5.27	231.64	-316.4	-158.20	-6.23
73.....	167.59	-275.9	-137.95	-5.43	232.66	-326.6	-163.30	-6.43
74.....	168.46	-284.6	-142.30	-5.60	233.70	-337.0	-168.50	-6.63
75.....	169.30	-293.0	-146.50	-5.77	234.73	-347.3	-173.65	-6.84
76.....	170.09	-300.9	-150.45	-5.93	235.75	-357.5	-178.75	-7.04
77.....	170.97	-309.7	-154.85	-6.10	236.77	-367.7	-183.85	-7.24
78.....	171.80	-318.0	-159.00	-6.26	237.77	-377.7	-188.85	-7.44
79.....	172.65	-326.5	-163.25	-6.43	238.78	-387.8	-193.90	-7.65
80.....	173.50	-335.0	-167.50	-6.59	239.79	-397.9	-198.95	-7.85

By graduating the free-lift scale bar to conform to the free lifts of balloons of various rates, this type of balance may be readily adapted to any ascensional rate, computed by any of the various formulas of the rate of ascent. Aside from the graduation of the free-lift scale bar, it is only necessary to make up the weight  $m$  to a mass of about one-half the sum of the maximum and minimum free lifts desired to be attained.

The best adjustment of the apparatus to give the greatest sensitivity and insure the greatest accuracy consists of the following: The hydrogen line support is set in the base of the balance on the back side, with the three-way stopcock toward the left-hand pan so that the reduced part is elevated from  $\frac{1}{4}$  to 1 inch above the connection on the nozzle assembly. The reduced arm of the nozzle assembly should be directed toward the fulcrum of the balance and about parallel with the three-way stopcock. When the  $\frac{3}{8}$ -inch rubber tubing is placed over the reducer and connected to the brass L it will then be supported mainly by the three-way stopcock, and any movement due to the oscillation of the balance will give a very slight torsion upon the 15-inch length of rubber tubing, the very principle upon which some of the most sensitive balances are constructed. The free-lift scale bar should be arranged so that the mid point of the bar is coincident with the fulcrum of the beam system.

In order to establish equilibrium throughout the beam system, it will be necessary to add a small amount of shot to the right-hand pan of the balance to counteract the weight of the nozzle assembly. A special recess, or basin, in the center of each pan is provided for this purpose. The finer adjustments of equilibrium can be made with the counterpoise weight mounted in the stem of the indicator over the fulcrum of the beam.

Using a filling apparatus to inflate to a definite rate of ascent is purely a mechanical operation. Having attached the hydrogen line to the short length of  $\frac{3}{8}$ -inch pipe on the hydrogen line support, figure 2, see that the three-way stopcock is open to admit the gas to pass to the nozzle. Then move the rider to the mid point of the free-lift scale bar, and see that the weight  $m$  is removed from the beam system. With the apparatus thus set, see that the beam system is in equilibrium and oscillates freely when unloaded; the counterpoise weight over the fulcrum will assist in this operation. This final adjustment should be tested for, and made if necessary, before each balloon is inflated.

After folding and rolling the balloon to expel the residual air, as explained in section 3, of *Instructions for Aerological Observers*, under *Inflation*, stretch the neck over the rim of the nozzle and lay the rolled portion of the balloon over the vent of the nozzle. The loose portion of the balloon should not be allowed to hang over the edge of the pan. Weigh the balloon by placing the small weights upon the right-hand pan of the balance, at

the same time noting that the 20-gram rider is set with the index over the mid point of the free-lift scale bar. Caution: To determine the accurate weight of the balloon, the weight  $m$  must be removed from the left-hand pan of the balance and the 20-gram rider must be set on the mid point of the scale bar. After determining the weight of the balloon in grams, move the rider to the corresponding graduations on the free-lift scale bar, remove the small weights from the right-hand pan, and attach the weight  $m$ . The setting is now complete for the definite inflation of that weight of balloon. For example, suppose that a balloon to be inflated to 200 m./min. was found to weigh 37 grams. The weights, by which the mass of the balloon was determined would be removed from the right-hand pan of the balance, the weight  $m$  (200 grams) would be placed in its designated position, and the rider would then be moved from its position at the mid point of the free-lift scale bar to the division 37. (See fig. 2.) The filling apparatus would then be set for the definite inflation of 200 m./min. for a balloon weighing 37 grams.

The application of the weight  $m$  will depress the left-hand pan of the balance and offer 2,000 gram-centimeters of force resistance to that side of the beam system. To support this weight it would require an inflation amounting to 200 grams free lift, but, by reference to Table 1, we need but 191.88 grams free lift to inflate a balloon weighing 37 grams to a rate of 200 millimeters. Thus, we have a difference of 81.2 gram-centimeters of force to overcome with the 20-gram rider. Now then by moving this rider to a position 40.6 millimeters (or 1.60 inches) to the right of mid-point of free-lift scale bar, the difference in moments of force would be accounted for.

When these settings are complete, the gas is turned on at the tank until equilibrium of the beam system is again established, then the gas is turned off. If too much gas is admitted to the balloon, the excess may be removed by opening the three-way stop cock, allowing it to escape into the air. The pressure of the gas in the balloon will be sufficient to drive out the excess, thus allowing a close adjustment of equilibrium of forces. The balloon is now sealed as instructed in Section 3 of *Instructions for Aerological Observers under Sealing*, and is in readiness for the observation.

A study of the sensitivity of the balance has shown it to be 1/10 gram or less. It is obvious that closer measurements of free lift can be made with the filling apparatus than is being made by the method of indefinite inflation. By the latter method, weights and free lifts are made only to the nearest whole gram, but by the definite method the graduations of the free-lift scale bar have been worked out to the hundredth part of a gram and graduated accordingly. Thus for a balloon of given weight one is enabled to inflate it to the nearest hundredth of a gram of free lift to attain a definite rate of ascent.

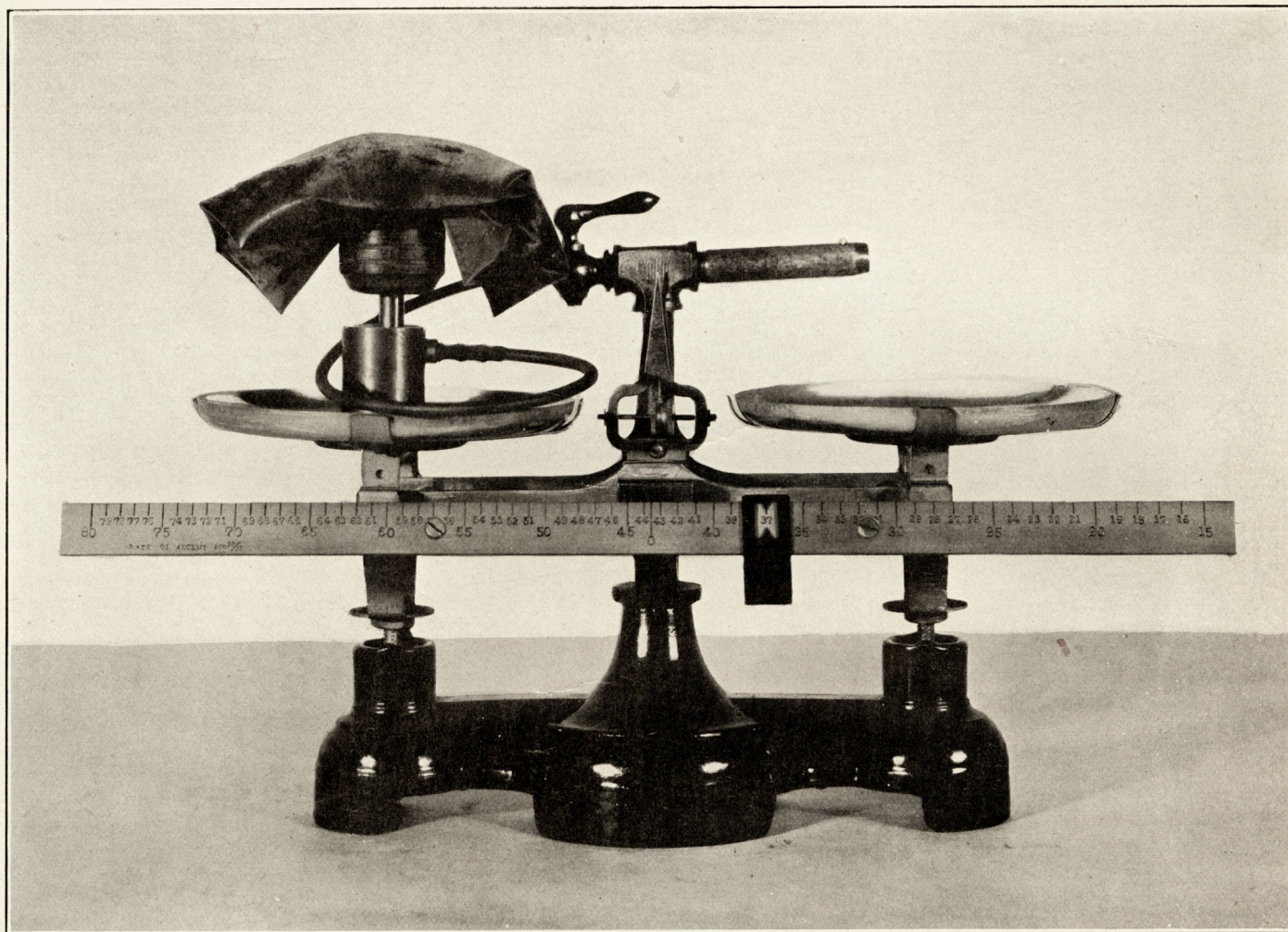


FIG. 2.—Filling apparatus with uninflated balloon attached.